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SHORT NOTE

Improved UT1 predictions through low-latency VLBI observations

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Abstract The quality of predictions of Earth orientation parameters (EOPs) in general, and of Universal Time (UT1) in particular, depends strongly on the time delay between the last observation available and the first prediction. Since 30 September 2007 (MJD 54373), the latency of UT1 results from a subset of single baseline VLBI observations running once per week (Mondays) has been decreased from 2 to 3 days to about 8 h. This was achieved by transmitting the raw VLBI data of 1-h duration from the observing sites in Tsukuba (Japan), Wettzell (Germany) and Ny-Ålesund (Norway) to the correlator of the Max-Planck-Institute for Radio Astronomy and the German Federal Agency of Cartography and Geodesy at Bonn, Germany, by high-speed Internet connections (e-Transfer). The reduced latency of the observations has improved the accuracy of the combined International Earth Rotation and Reference Systems Service (IERS) Rapid Service/Prediction Center (RS/PC) UT1-UTC solution by roughly 50% on the days when the data are available. Because this combination is an input to the UT1-UTC prediction process, the improved latency is also responsible for a roughly 21% improvement in the accuracy of short-term IERS RS/PC UT1-UTC predictions on the days where the data are available.

Keywords UT1 predictions · VLBI Intensive observations

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1 Introduction

Very long baseline interferometry (VLBI) observations are among the primary sources of information for the combination and prediction of the Earth's rotation angle which is expressed by Universal Time (UT1). The International VLBI Service for Geodesy and Astrometry (IVS) (Schlüter and Behrend 2007) devotes significant resources to carrying out and analyzing daily observations of approximately 1-h duration, called Intensives, on baselines between Tsukuba (Japan) and Wettzell (Germany) as well as between Kokee Park (Hawaii, USA) and Wettzell (Fig. 1) (e.g. Nothnagel and Schnell 2008).

As of May 2009, the raw data of Kokee Park observing with Wettzell on Mondays through Fridays at about 1830 UT in the "Int1" sessions are transported by disk to the correlator at the U.S. Naval Observatory in Washington D.C. while all other data are transmitted by Internet connections. VLBI data transmitted by Internet is usually referred to as electronic transfer or e-Transfer, while electronic VLBI (e-VLBI) is used to describe real-time correlation of e-transferred data. The surface transport of the data by courier service causes a delay of about 2–3 days, on an average, before the data can be correlated and analyzed.

The "Int2" sessions (Nothnagel and Schnell 2008) are observed every Saturday and Sunday at 0700 UT on the Tsukuba–Wettzell baseline and the data are transmitted to the Tsukuba correlator by Internet connection. A delay of at least one full day, however, is incurred for these sessions as well since correlation is only carried out on Monday mornings (Japanese time) after the weekends.

To reduce delays in raw data delivery to a minimum and to fill the gap between Sunday 0700 UT and Monday 1830 UT, a new type of session has been devised for Monday mornings (0700 UT) called "Int3." For these experiments, the

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14. ABSTRACT
The quality of predictions of Earth orientation parameters (EOPs) in general, and of Universal Time (UT1) in particular, depends strongly on the time delay between the last observation available and the first prediction. Since 30 September 2007 (MJD 54373), the latency of UT1 results from a subset of single baseline VLBI observations running once per week (Mondays) has been decreased from 2 to 3 days to about 8 h. This was achieved by transmitting the raw VLBI data of 1-h duration from the observing sites in Tsukuba (Japan),Wettzell (Germany) and Ny-?esund (Norway) to the correlator of the Max-Planck-Institute for Radio Astronomy and the German Federal Agency of Cartography and Geodesy at Bonn, Germany, by high-speed Internet connections (e-Transfer). The reduced latency of the observations has improved the accuracy of the combined International Earth Rotation and Reference Systems Service (IERS) Rapid Service/Prediction Center (RS/PC) UT1-UTC solution by roughly 50% on the days when the data are available. Because this combination is an input to the UT1-UTC prediction process, the improved latency is also responsible for a roughly 21% improvement in the accuracy of short-term IERS RS/PC UT1-UTC predictions on the days where the data are available.

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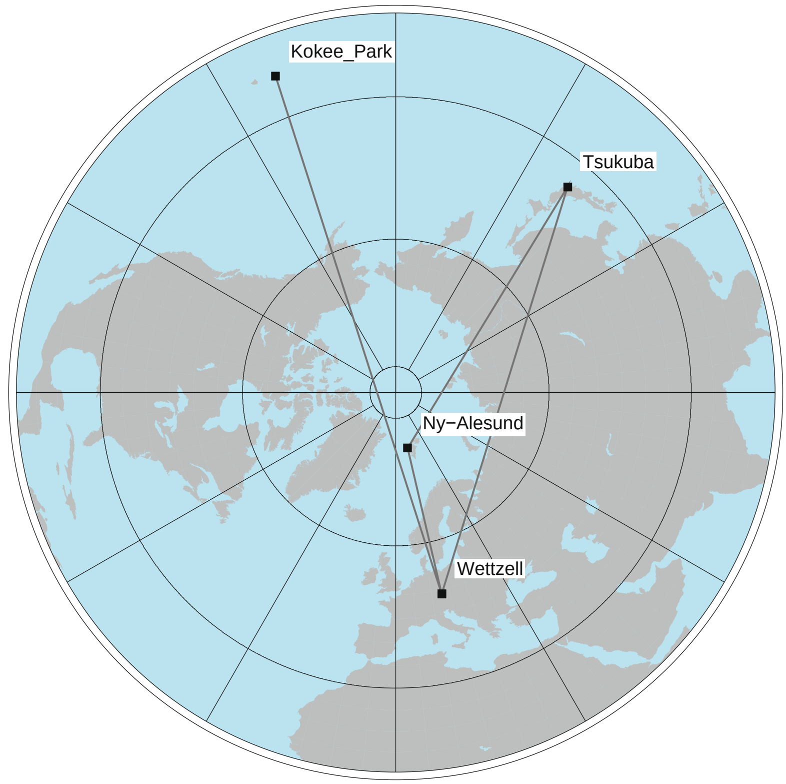

Fig. 1 Baselines employed for regular UT1-UTC determinations: Int1 Wettzell-Kokee Park, Int2 Wettzell - Tsukuba, Int3 Wettzell - NyAlesund-Tsukuba

telescopes at Ny-Ålesund, (Spitsbergen, Norway), Tsukuba and Wettzell simultaneously observe for about 1 h and the data are transferred to the Max-Planck-Institute for Radio Astronomy (MPIfR) and the German Federal Agency of Cartography and Geodesy (BKG) correlator at Bonn, Germany on public Internet lines immediately. The transfers last about 0.5 h for data from Tsukuba and Wettzell on 300–500 Mbit/s lines and about 1 h for data from Ny-Ålesund on a 90 Mbit/s line. Correlation starts immediately after the transfers are completed. In general, the process is completed by about 1500 UT the same day and the analysis results are available about 1 h later.

For completeness, it should be mentioned that since 2007 Japanese, Swedish and Finnish colleagues have been running about 60 ultra-rapid UT1 observing sessions on baselines between Japan and Europe successfully (Haas et al. 2007; Matsuzaka et al. 2008; Sekido et al. 2008). In experimental setups, they were able to provide some of the UT1 results within 30 min after the end of the 1-h observations (Matsuzaka et al. 2008). Unfortunately, in none of these cases, the results were fed into the regular IVS analysis chains and results have not been submitted to the International Earth Rotation and Reference Systems Service (IERS) Rapid Service/Prediction Center (RS/PC). Therefore, none of these sessions had any impact on routine UT1 predictions.

In this paper, we will concentrate on the prediction aspects and the impact which the currently available, regularly determined UT1 results of the Int3 sessions have on the prediction process at the IERS Rapid Service and Prediction Center. Details of the observing sessions in terms of scheduling, data transfer, correlation and analysis are dealt with in other publications (e.g., Robertson et al. 1985; Ray et al. 1995; Nothnagel and Schnell 2008; Sekido et al. 2008). Further studies or simulations of what effects on the predictions can be expected from a possible reduction in latency below 30 min are beyond the scope of this Short Note.

2 UT1-UTC predictions with Int3

The US Naval Observatory acts as the International Earth Rotation and Reference Systems Service (IERS) Rapid Service/Prediction Center (RS/PC). It is responsible for providing accurate combined and predicted Earth orientation parameters (EOPs) to the international community for real-time users. One of the main obstacles is that the analysis results of the space-geodetic observations are always delayed between one and a few days. The prediction methods for UT1-UTC used by the IERS RS/PC involve the use of atmospheric angular momentum (AAM) forecasts for predictions out to 7 days and the use of autoregressive algorithms for longer periods (Luzum et al. 2009 and the publications referenced therein). For more information on the autoregressive algorithm used, see McCarthy and Luzum (1991), while for

Table 1 Statistical measures of the differences in the UT1-UTC combination and 1-day prediction between those solutions with rapid turnaround intensives and those without

Extract of data points	IERS RS/PC product	# of occurrences	rms error(μs)	min/max (μs)
Standard data (excl. Int3)	Rapid combination	790	53	−144/159
	Prediction	789	121	−332/362
Rapid data (Int3)	Rapid combination	61	23	−84/49
	Prediction	61	95	−220/159

# of occurrences number of combined/predicted data points, *rms error* rms difference with respect to the reference solution, *min/max* minimum/maximum deviation from reference solution

The number of data points for the standard solutions and standard predictions is different because the last predicted data point can only be compared with itself and is, therefore, excluded from the statistics

more information on the IERS RS/PC use of AAM forecasts for predicting UT1-UTC, see Johnson et al. (2005).

Since the beginning of the Int3 series, 106 sessions have been observed and analyzed with 61 of them being available within 8 h after the observations. The analysis below starts with the data on 30 September 2007 (MJD 54373), which is roughly the first occurrence of a rapid turnaround Intensive session, and ends on 27 January 2010 (MJD 55223).

For our analysis of the impact of the rapid turnaround Intensives (Int3) sessions, the archived daily solution files of the IERS RS/PC are segregated into those created with Int3 data (labeled “rapid data”) and those without (labeled “standard data”). These results are then compared with the IERS RS/PC current best estimate of EOPs which is the IERS RS/PC Weekly Solution of 28 January 2010 (reference solution). For each daily solution, the UT1-UTC differences between the reference solution and the last day of combination as well as the first (1-day) prediction are computed and separately accumulated in an rms sense (Table 1).

The number of solutions created with rapid turnaround Intensives is of course only a fraction of the solutions with standard data (61 vs. 790). However, the daily combination solutions with rapid data show a noticeable improvement (roughly a factor of 2) over the combinations with standard data alone, a change that is significant at more than the 99% level (based on an F statistic). The estimated error of the combination with rapid data (23 μs) is close to the estimated accuracy of the Intensives themselves (∼15 μs) indicating that the combination is close to obtaining the maximum estimated improvement to be expected from rapid turnaround Intensives. The UT1-UTC estimate for the last day of the combination solution still has a slightly larger error than estimates for preceding days. This is because other information that might be incorporated (e.g. GPS and AAM data) in the combination solution is not yet available to determine the value and the rate of change of the UT1-UTC on the last day.

Even more important is the fact that the 1-day predictions using the rapid data show an improvement over the 1-day predictions with the standard data set of approximately 21% bringing the average prediction error down to 95 μs, a change that is significant at the 99% level (based on an F statistic). This reduction in prediction error justifies the resources and efforts that have to be invested to achieve the 8-h latency.

The rapid increase in error between the last combination point and the first prediction point is larger than would be anticipated. This increase in error is dominated by the error in the 1-day length of day (LOD) prediction error provided by AAM forecasts of approximately 60 μs (Brockett et al. 2007). This information is a significant contributor to short-term predictions of the IERS RS/PC (Luzum et al. 2009). Assuming only random sources of error, the 1-day prediction would be expected to be the root sum square of the contributing errors, i.e. the measurement noise of the observation 15 μs and the inaccuracy of the forecasts 60 μs. In other words, the 1-day prediction error should be <70 μs. The difference between the theoretical expectation and the observed error may indicate that the current use of AAM forecasts in the IERS RS/PC prediction is not optimal. Possible improvement in the IERS RS/PC prediction is a topic that deserves further investigation.

3 Conclusion

Including rapid turnaround Intensives, made possible through the use of e-Transfer, in the current IERS RS/PC operational procedure produces a noticeable improvement in accuracy of both the combination and the prediction solution. The improvement in the combination appears to be consistent with the expectations based on the quality of the data, but the improvement in the prediction appears to be smaller than anticipated. These results demonstrate the importance of reduced latency data to the Earth orientation combination and the prediction process, in general. They also indicate the value of e-Transfer to the real-time Earth orientation community.

When considering the benefits, all endeavors should be concentrated on reducing the latency to less than one hour. As e-Transfer and e-VLBI become integrated more fully into the operations of the geodetic VLBI community, similar

improvements in real-time EOP determination and prediction should be feasible on a more regular basis. In this context, the possibilities as demonstrated by Japanese and Swedish colleagues as referred to above should be exploited further including the establishment of reliable data streams to the IERS Rapid Service and Prediction Center.

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